Synthesizing Bidirectional Texture Functions For Real-World Surfaces

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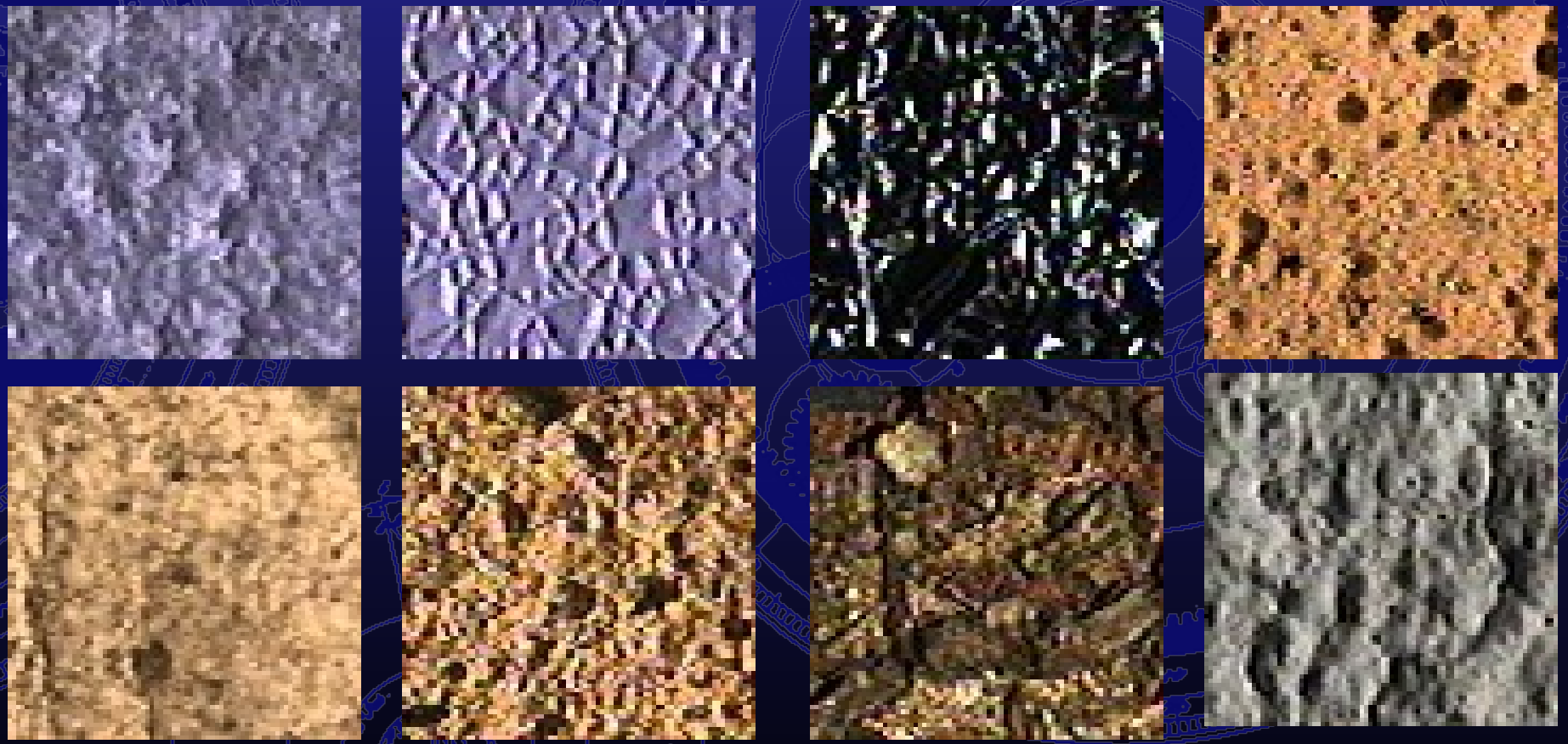
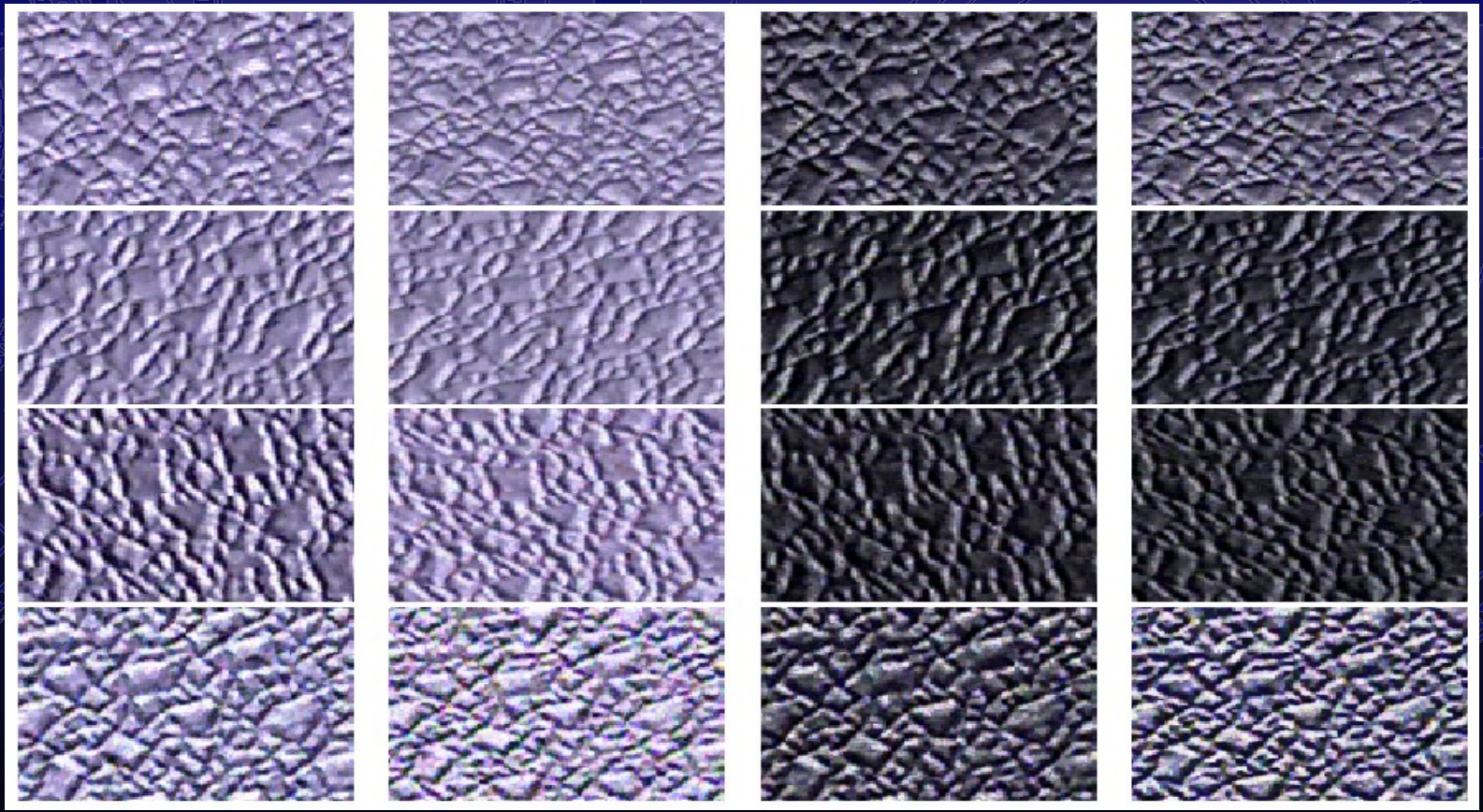
Real-World Surfaces



CUReT Database [Dana et. al. 97]

Under Different Lighting/Viewing Directions



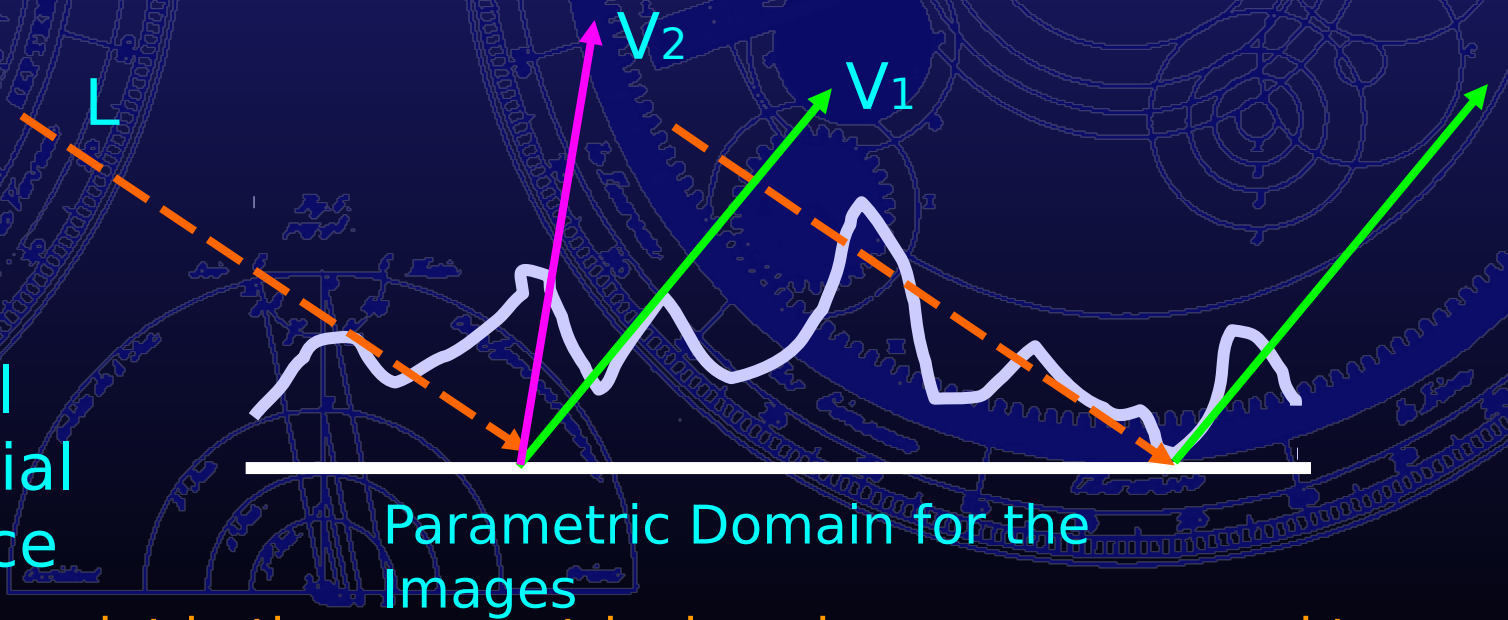
Appearance Models

- **BRDFs**
  - Surface microstructure
- **Reflectance Maps**
  - Heterogeneous surface microstructure
- **Bump/Displacement Maps**
  - Heterogeneous surface mesostructure
- **Bidirectional Texture Functions**
  - Both microstructure and mesostructure

Bidirectional Texture Functions (BTF)

- **A collection of images of the same surface under different lighting and viewing directions**
  - [Dana, Ginneken, Nayar & Koenderink 97]
  -

$$L \times V \rightarrow I$$



The same point in the parametric domain may correspond to different points on the material surface from different viewpoints.

Why BTF?

- **Visual Effects from Small-Scale Geometric Details (3D Textures)**
  - Shadowing
  - Occlusion and foreshortening
  - Spatially varying normal orientations
  - Inter-reflection
- **Spatially Varying Reflectance Properties**

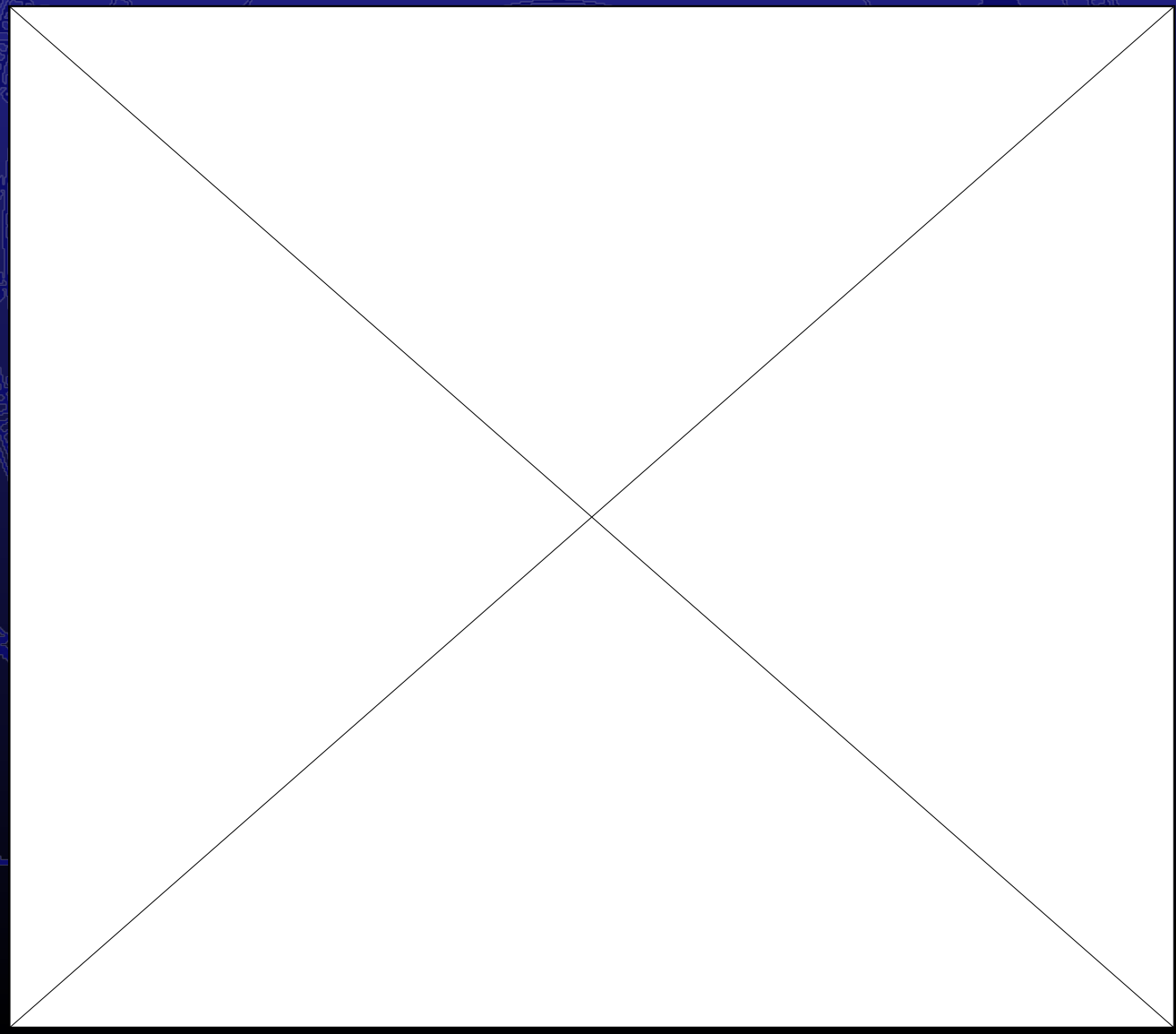
The Problem

- **Acquiring a dense set of images in a 4D space is extremely expensive.**

- **Our Approach: BTF Synthesis**
  - To generate a continuous BTF
  - From a sparse set of images
  - Under any lighting/viewing setting

Related Work I

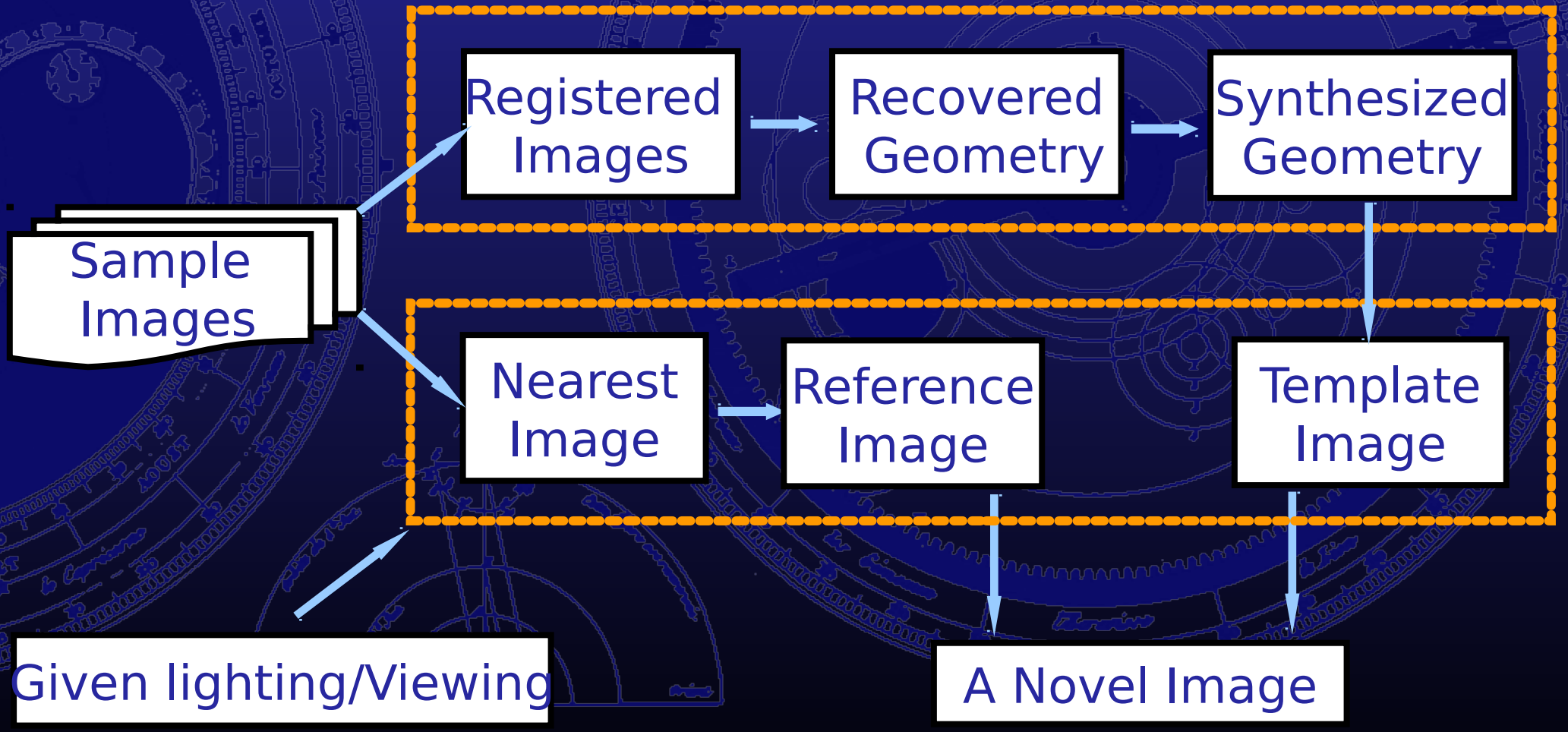
- **CUReT Database**
  - Sparse sampling: 205 images in 4 dimensions
  - Unevenly covering the lighting/viewing space
  - http://www.cs.columbia.edu/cave/curet/



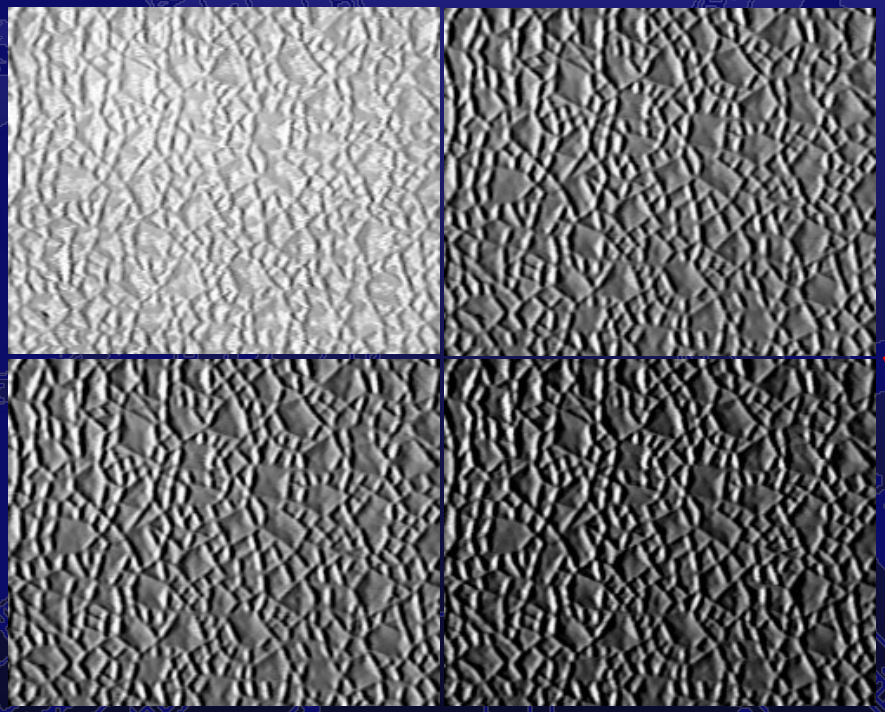
Related Work II

- **BTFs and 3D Textures**
  - [Dana et. al. 97, 99], [Leung & Malik 99]
- **2D Texture Synthesis**
  - [Heeger & Bergen 95], [De Bonet 97], [Simoncelli & Portilla 98], [Zhu, Wu & Mumford 98], [Efros & Leung 99], [Wei & Levoy 00] ….
  - Patch-base texture synthesis [Xu, Guo & Shum 00]
- **Recovering Normal Maps**
  - [Rushmeier et. al. 97]

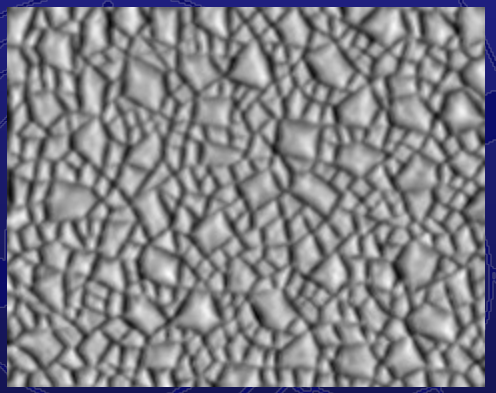
Overview of BTF Synthesis



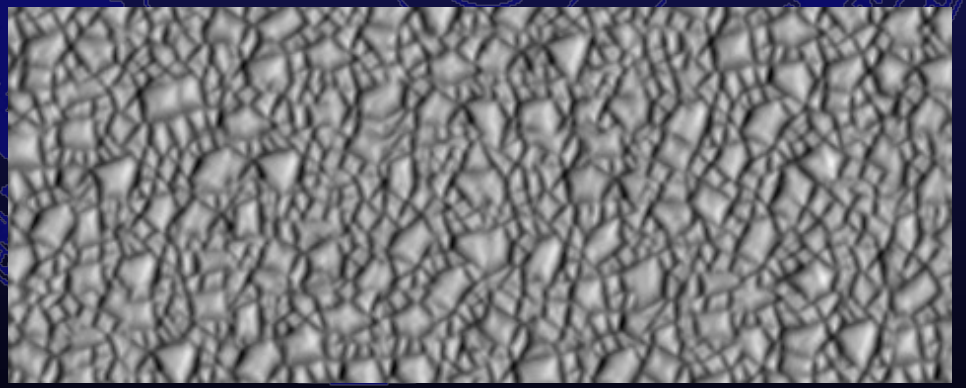
Geometry Recovery and Synthesis



Input: registered images with varying lighting directions



Recovered geometry



Synthesized geometry

Shape from Shading

- **Shape from Shading through Normals**
  - E.g., [Horn & Brooks 86]
- **Direct Height from Shading for Lambertian Surfaces [Leclerc & Bobick 91]**

$$E = \sum_{i,j} [\alpha \cdot (\rho \cdot R(p_{ij}, q_{ij}) - I(i,j))^2 + \lambda \cdot (u_{ij}^2 + v_{ij}^2)]$$

$$R(p_{ij}, q_{ij}) = \vec{n}_{ij} \cdot \vec{L} = (x_L \cdot p_{ij} + y_L \cdot q_{ij} - z_L) / \sqrt{p_{ij}^2 + q_{ij}^2 + 1}$$

Knowns

$I(i,j)$ x_L y_L z_L

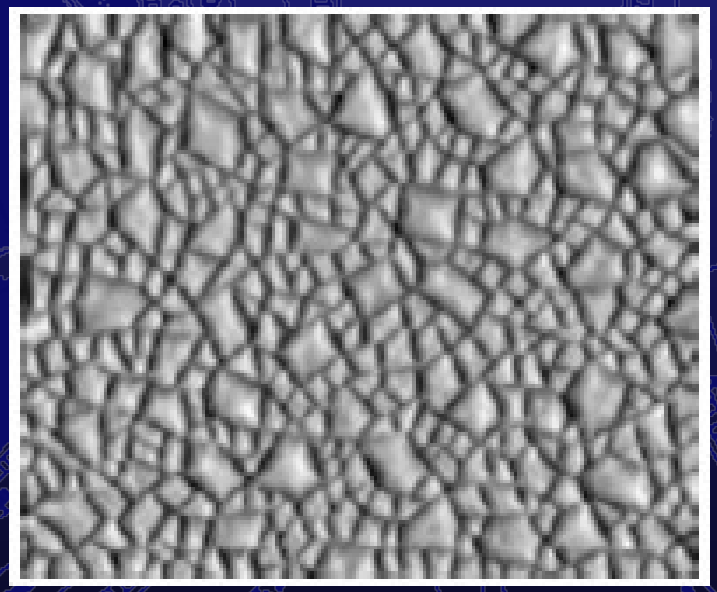
Unknowns

ρ $p_{i,j}$ $q_{i,j}$

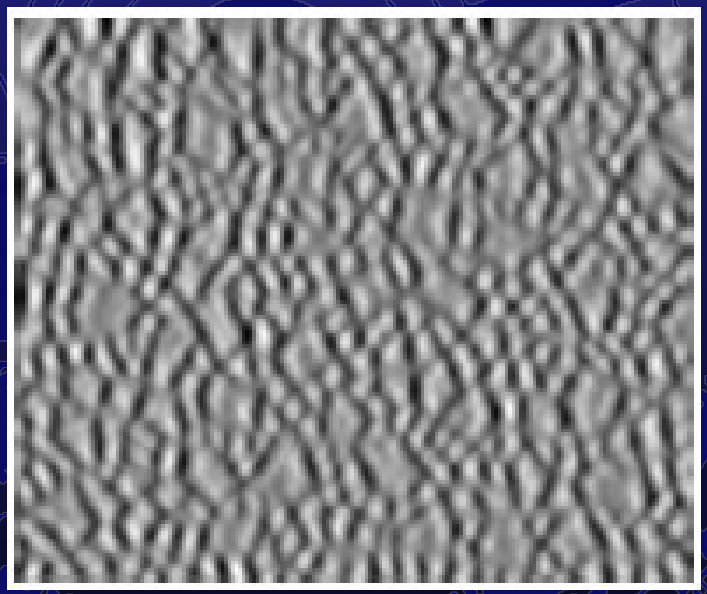
Modified Height from Shading

- **Modifications**
  - Pixel-wise albedo function
  - Shadow pixel classification
  - Adaptive geometry smoothness
  - Using multiple input images

A Comparison of Recovered Geometry



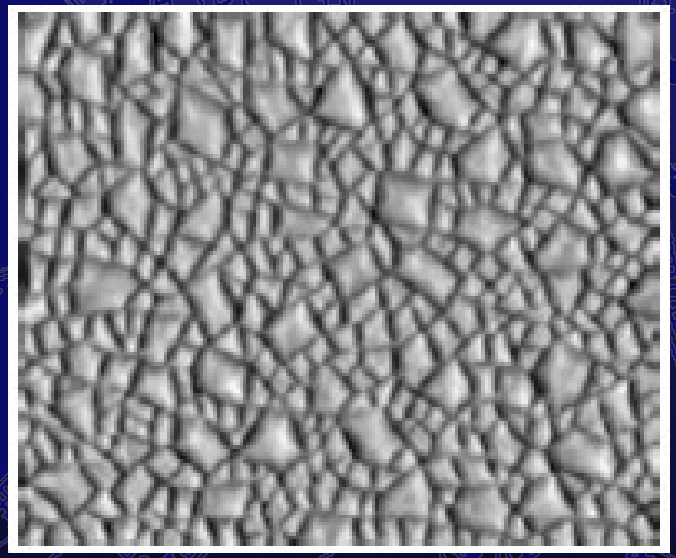
Modified



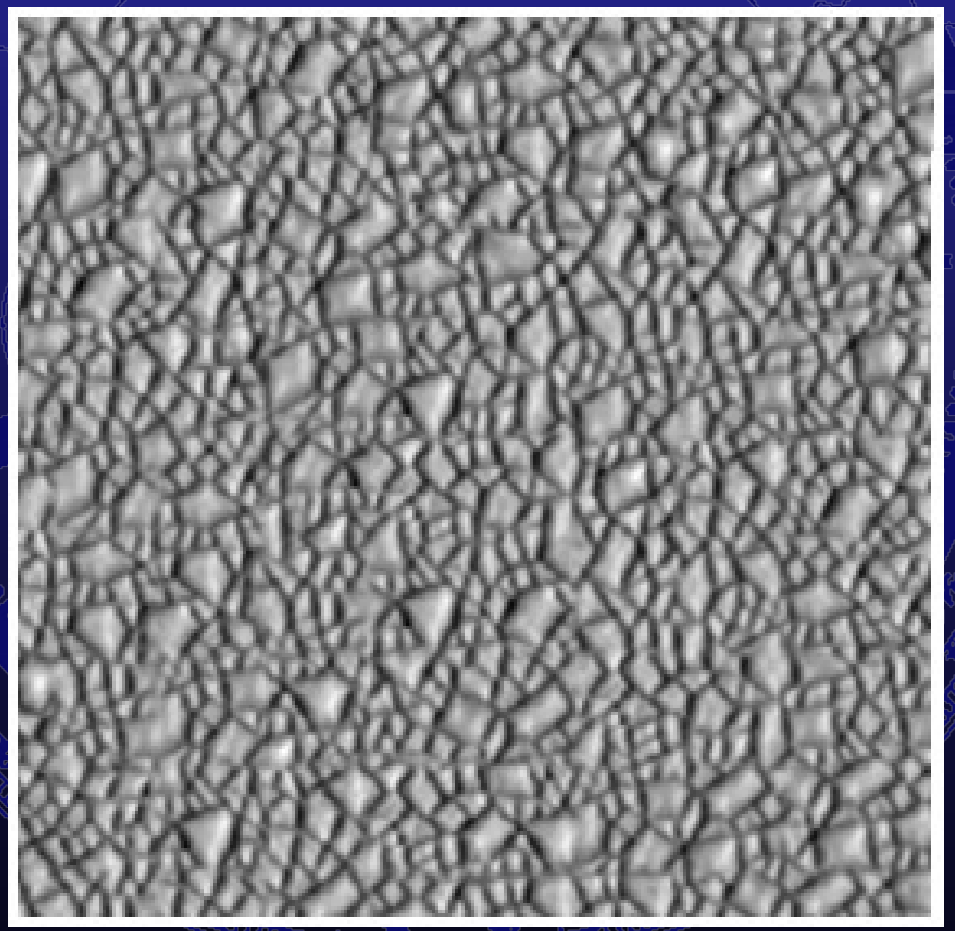
Leclerc & Bobick

These images are gray-scale coded

Geometry Synthesis



Recovered

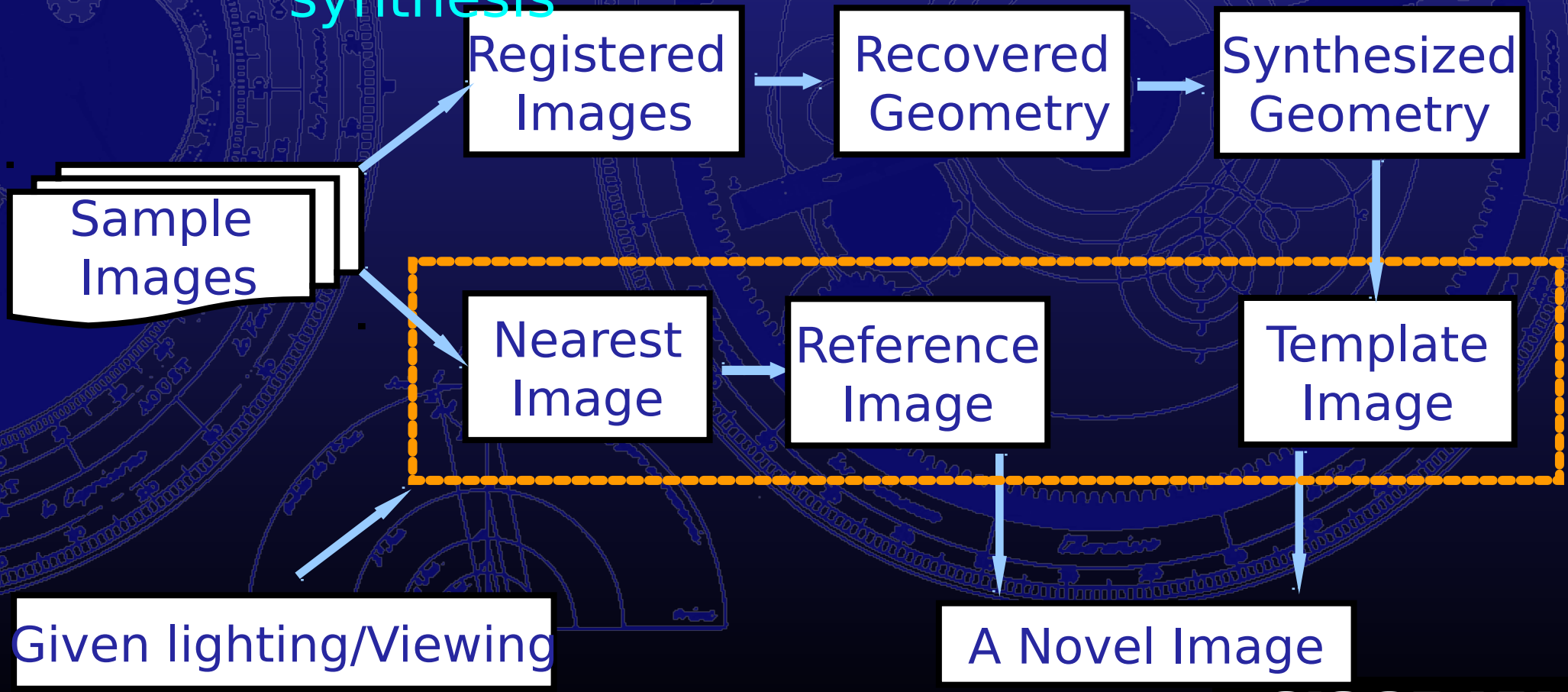


Synthesized

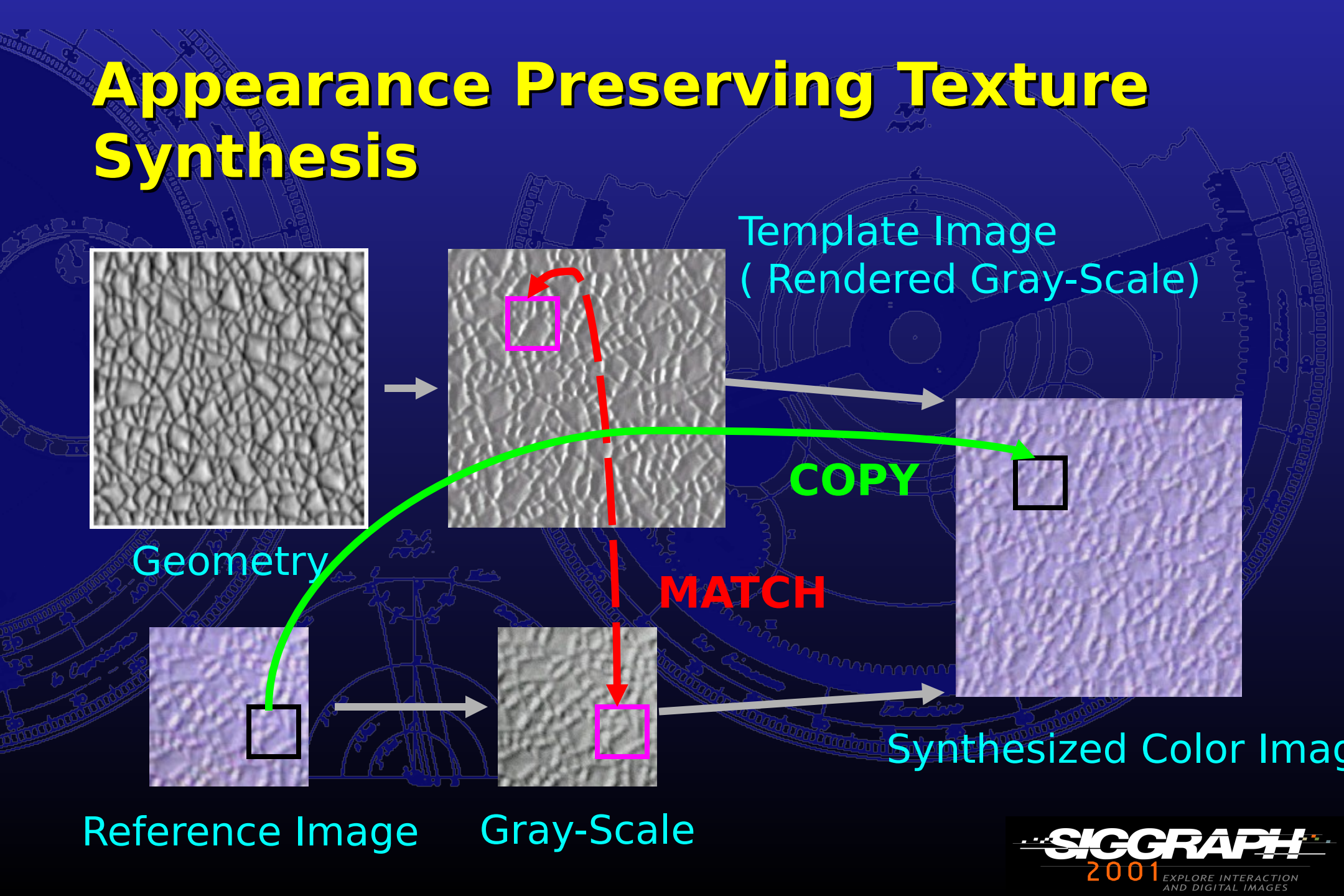
- Patch-based sampling

Overview of BTF Synthesis

Appearance preserving texture synthesis



Appearance Preserving Texture Synthesis



Template Image and Reference Image

Template Image

- Rendered from synthesized geometry given lighting/viewing
- Correct occlusion, fore-shortening, and shadows
- Approximate shading

Reference Image

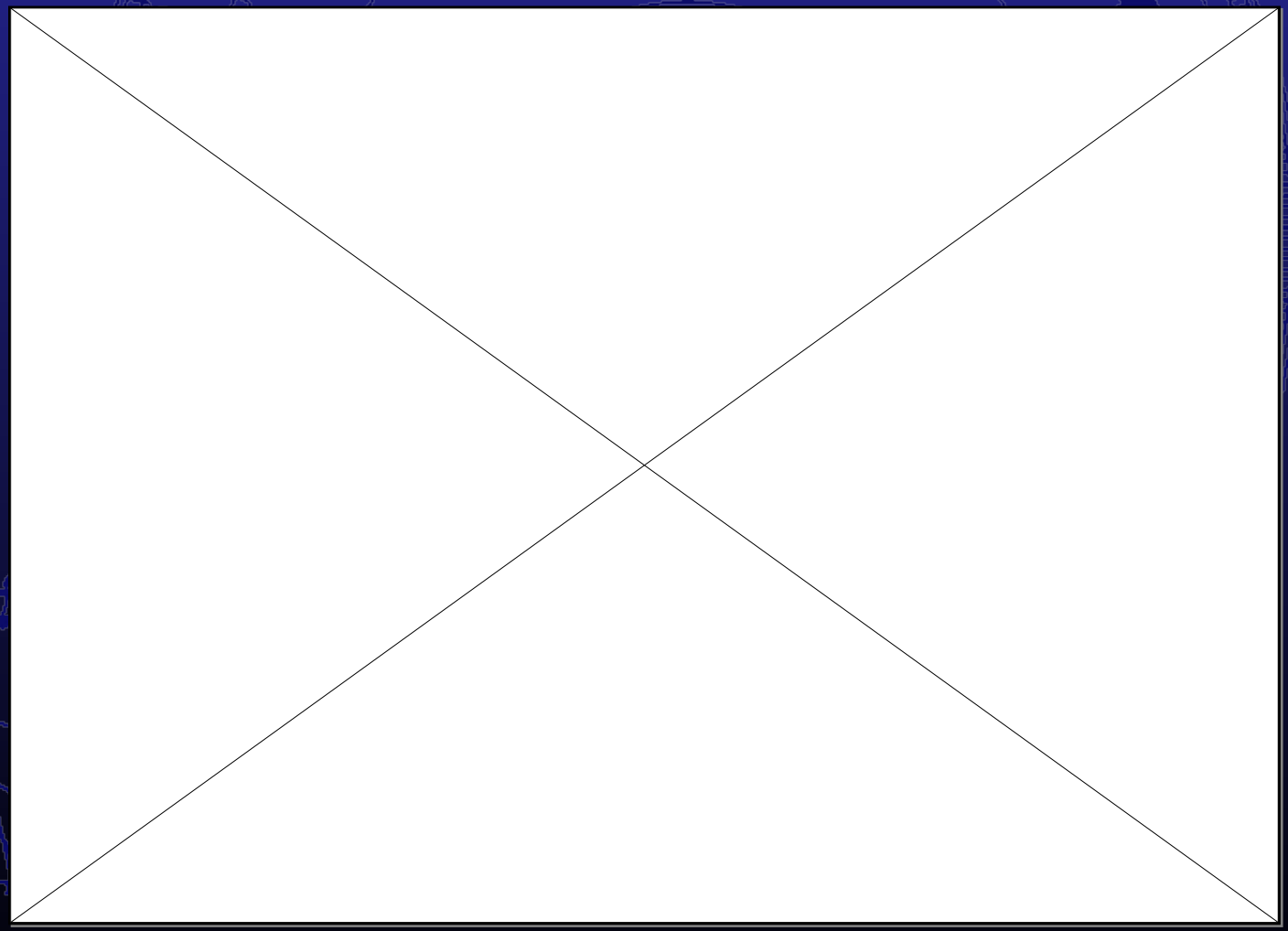
- Taken from the database with same lighting/viewing setting
- Correct color and shading variations
- Inconsistent geometry with the template image

Reference Image Generation

- **Pick one of the “nearest” sample images**
  - Closest viewing and lighting directions
  - Isotropic materials: “closest” under rotation
- **Warp it to the current viewing/lighting setting**
  - Fore-shortening
    - *Tilting angle of the viewing direction*
  - Lighting effects
    - *Azimuth angle of the lighting direction*

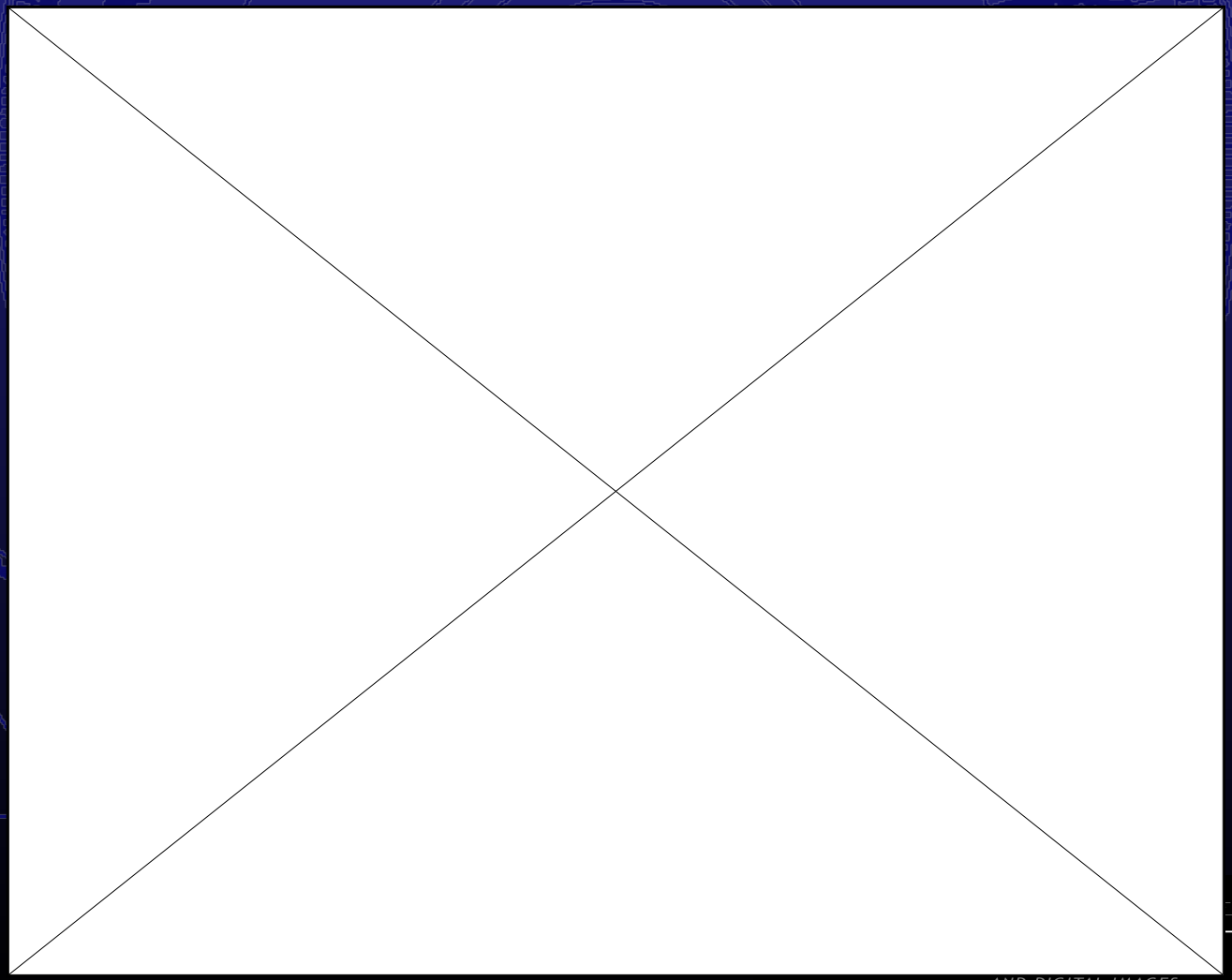
Three-step Warping Method

- Back-project onto the material surface plane
- Align light azimuth by rotation in the material surface
- Re-project onto the desired viewing plane



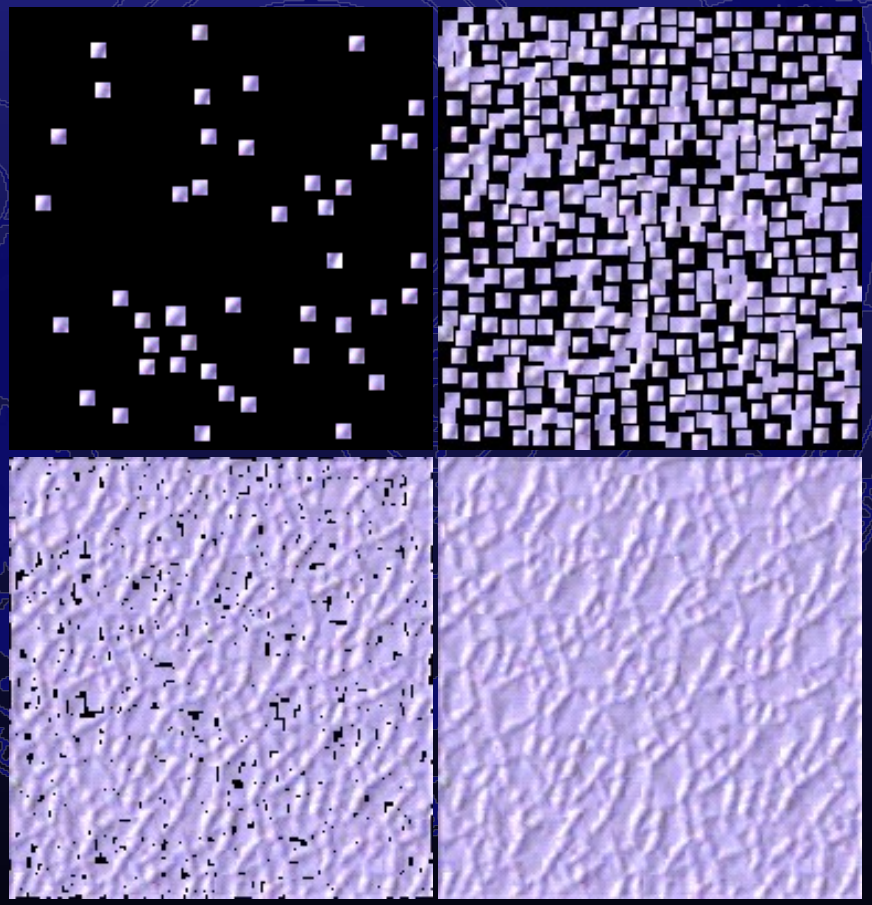
Synthesizing Novel Image

- **Block Copying**
  - Select a block from the template image
  - Find its best match in the reference
  - Copy the patch onto the synthesized image

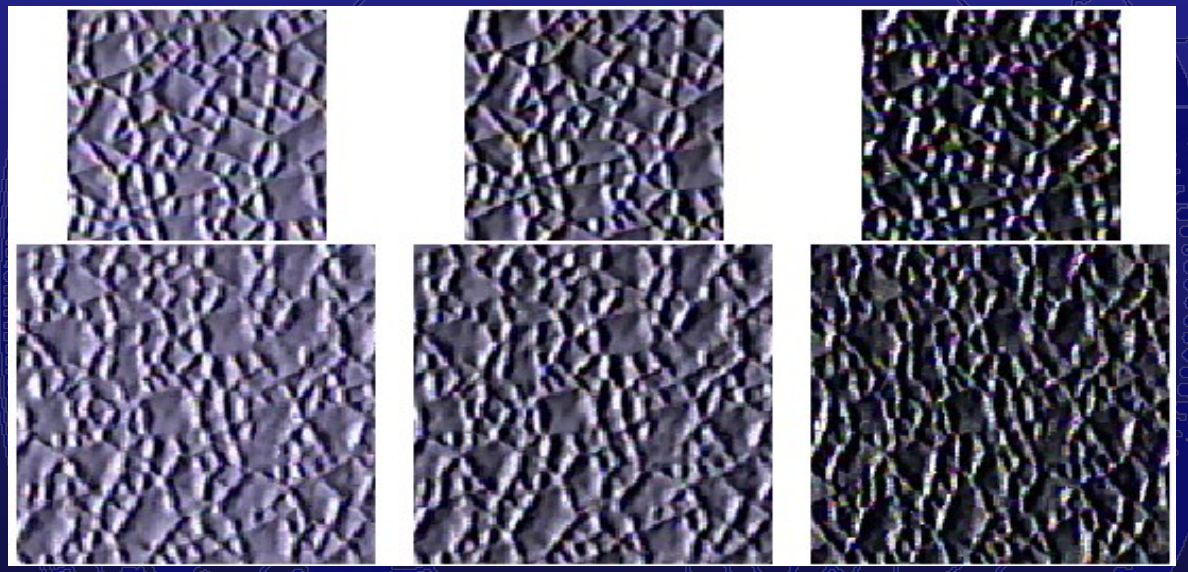


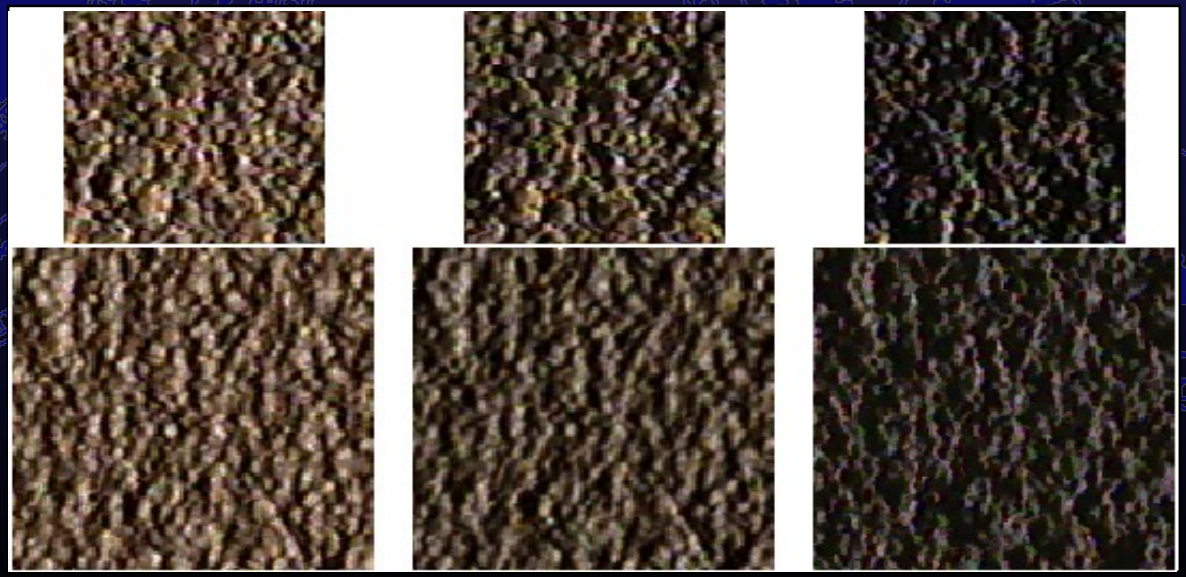
Block Copying

- **Details**
  - Feature ordering
    - *Best features fill first*
  - Feature matching
    - *Multiple block sizes*
  - Matching criteria
    - *Optimal block with normalized correlation*



Reference Images vs. Synthesized Textures





Two Synthetic Images with BTF Mapping

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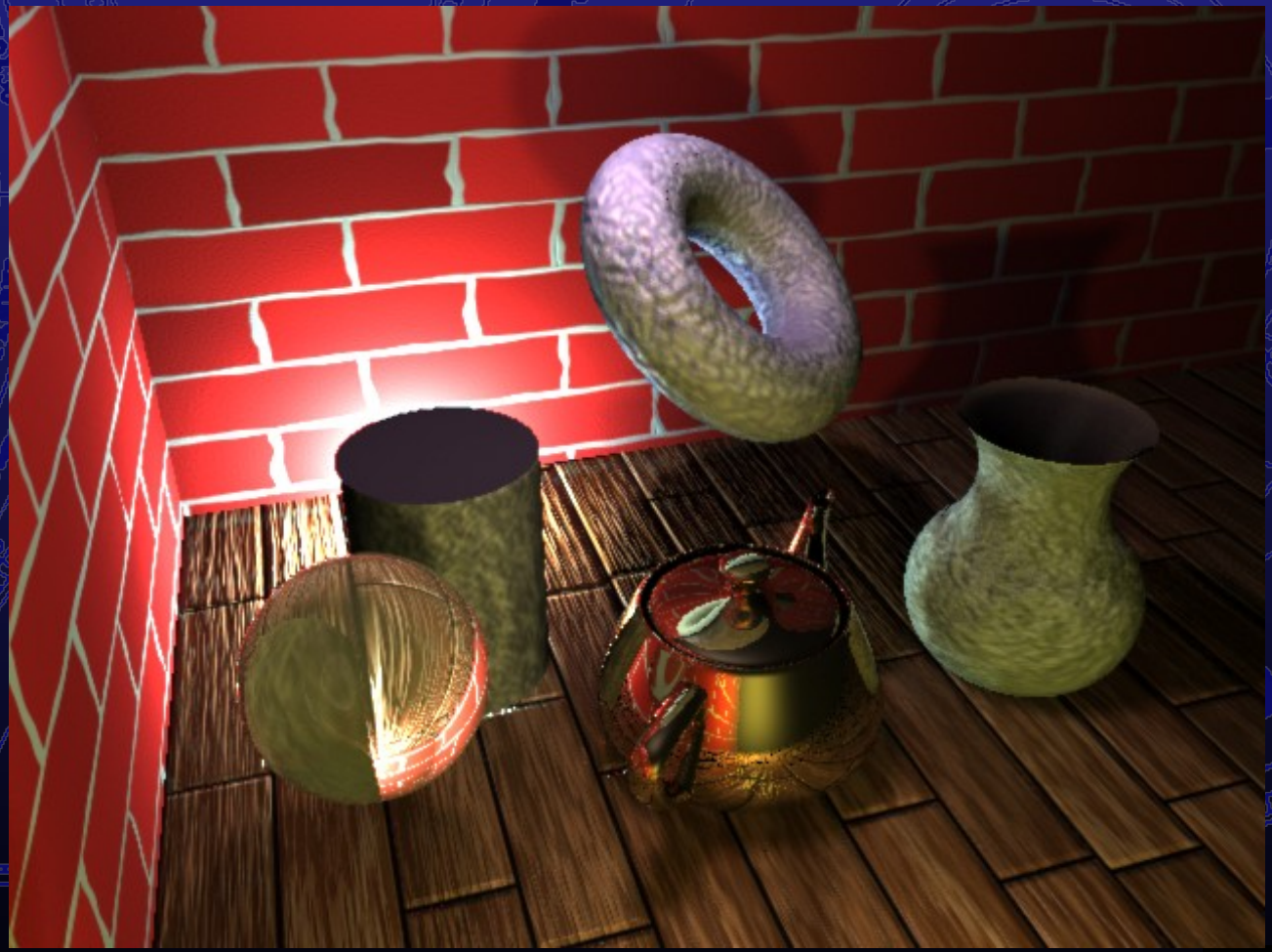
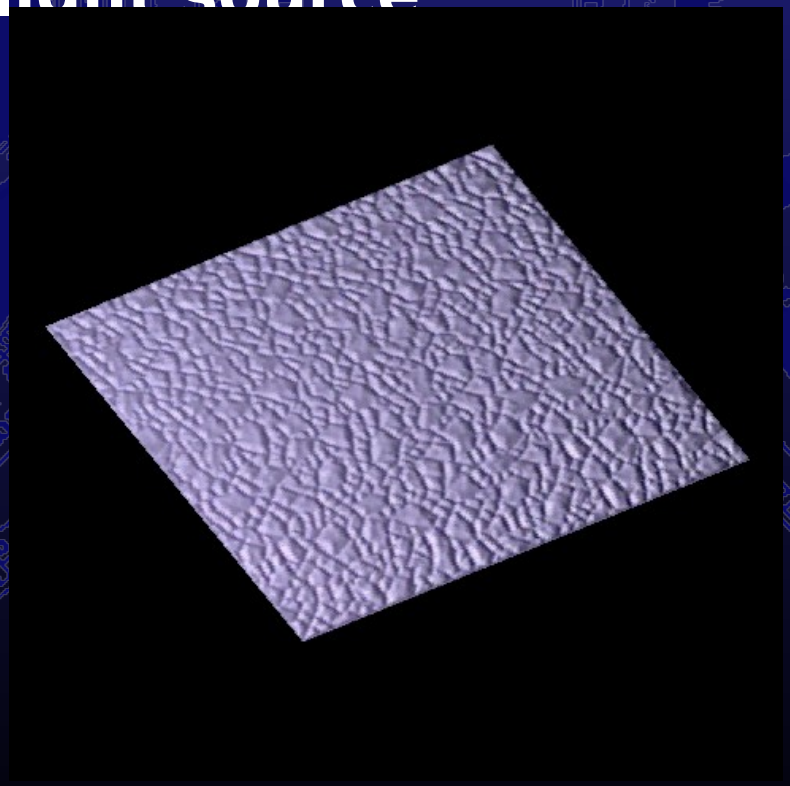
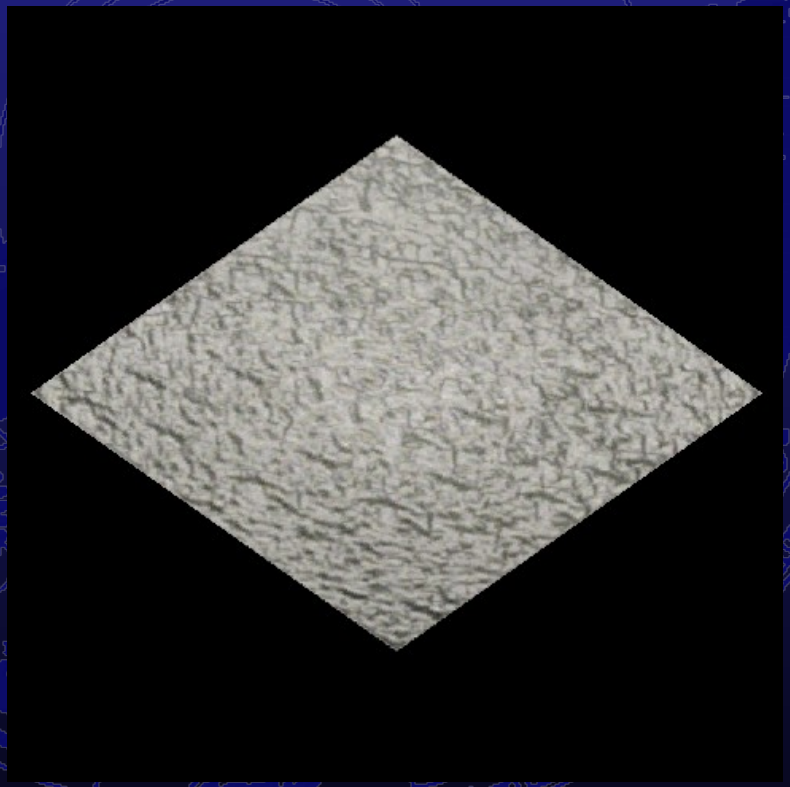


Video I

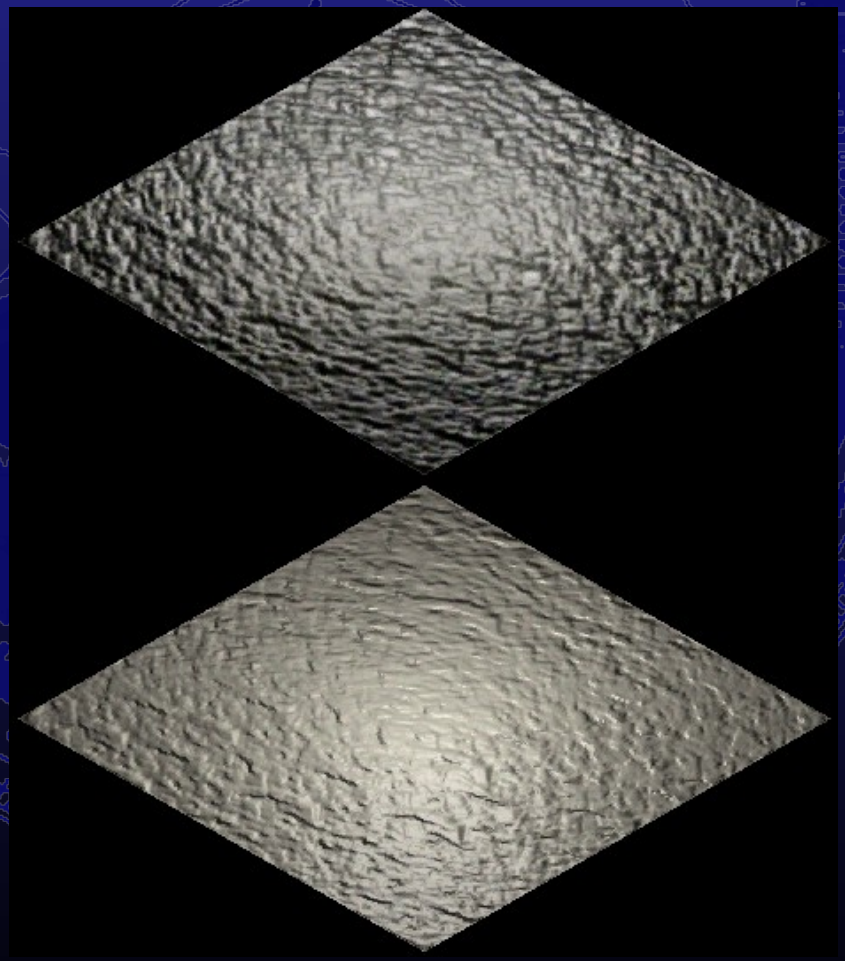
- Surface appearance with a moving point light source





Video II

- A comparison between BTF mapping and bump maping



Contributions

- **A novel hybrid approach for studying appearance models**
- **An algorithm synthesizing complete BTFs**
  - From a sparse set of sample images.
- **A method for recovering displacement maps from photographs of real world materials**
  - Modified shape-from-shading algorithm.

Acknowledgements

- Kristin Dana (CUReT)
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